

# Electronic Devices

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material. This produces a large current flow through the diode which increases as the applied voltage increases.

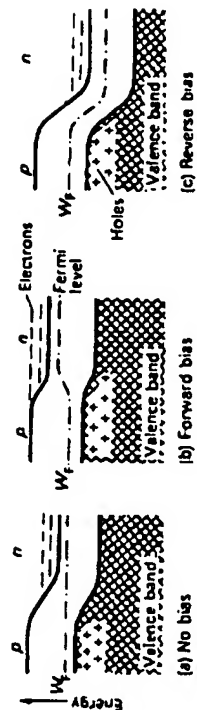


Fig. 28

When reverse bias is applied, the contact potential is increased as shown in Fig. 28(c) and the majority carriers are unable to cross the junction. Only a small number of minority carriers move across the junction due to their thermal energy and produce a small leakage current through the device. In Appendix D it is shown that the characteristic equation of current flow through the device is given by

$$I = I_s (e^{qV/kT} - 1)$$

where  $I_s$  is the reverse saturation current and  $V$  is the applied voltage. A typical plot of diode current  $I$  is shown in Fig. 29.

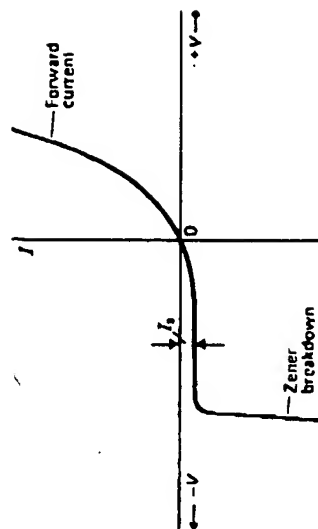


Fig. 29

Due to its rectifying property, large  $p$ - $n$  diodes are used for converting a.c. power into d.c. power, and at low power levels junction diodes are used as detectors in communication systems.

## 4

### Solid-state devices

The development of various semiconductor materials such as silicon and the improvement in manufacturing techniques, has led to the construction of a wide variety of solid-state devices. The most important of these devices will be considered now, in terms of their main characteristics and applications in the field of electronics.

#### 4.1 Semiconductor diodes

Various diodes now in use are the junction diode, Zener diode, varactor diode and tunnel diode. Some special diodes such as the Gunn diode, IMPATT and Trapatt diodes are described in Appendix F, while other semiconductor diodes like the photo-diode and light-emitting diode are described in Chapter 6.

##### Junction diode

An ordinary  $p$ - $n$  junction diode can be used for rectifying purposes because it conducts mainly in one direction only. To determine its current-voltage characteristic, consider a  $p$ - $n$  junction diode connected first with forward bias as shown in Fig. 27(a) and then with reverse bias as shown in Fig. 27(b).

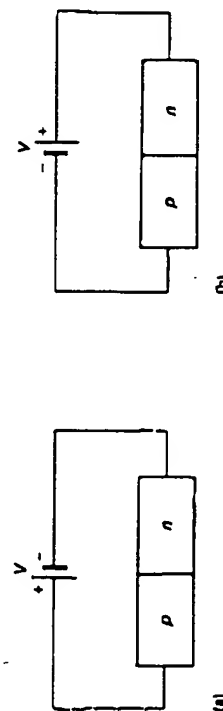


Fig. 27

With forward bias applied the contact potential across the junction is reduced as in Fig. 28(b). Holes in the  $p$ -type material move easily into the  $n$ -type material and electrons in the  $n$ -type material move easily into the  $p$ -type

## Zener diode

When a  $p$ - $n$  junction is reverse biased there is a large increase in current at a particular value of voltage. This is known as a *breakdown* phenomenon and there are two mechanisms causing this breakdown. The first is called the *Zener effect*<sup>12</sup> and the second is called the *avalanche effect*.<sup>13</sup>

In  $p$ - $n$  diodes which have thin, highly doped, abrupt junctions, the transition region is narrow and there is a large electric field in the junction region. This causes electrons to be pulled out from the lattice structure and the consequent breaking of the covalent bonds produces a large number of electron-hole pairs, which gives rise to a large current. The phenomenon usually occurs at voltages around 5 V or less and is called the *Zener effect*. An alternative explanation makes use of quantum principles and is called *tunnelling*. (See the 'tunnel' diode later in this section.)

In ordinary  $p$ - $n$  junctions at larger voltages, the electrons can also be accelerated to high energies and knock out other electrons from the lattice. These electron-hole pairs in turn produce further collisions and more electron-hole pairs are created. This carrier multiplication process is called the *avalanche effect*. It is illustrated in Fig. 30(a).

Around about 5 V the two effects tend to occur together and diodes which are designed to operate at about 5 V are called *Zener diodes*. They are used as voltage stabilisers because the voltage across them is remarkably constant over a wide range of current values. The diode also has a very low temperature coefficient and is therefore fairly insensitive to temperature changes. Moreover, the breakdown is not harmful if the diode dissipation is not exceeded. This is ensured by using a series resistor  $R$  to limit the current and is shown in Fig. 30(b).

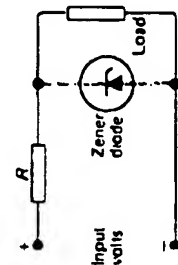
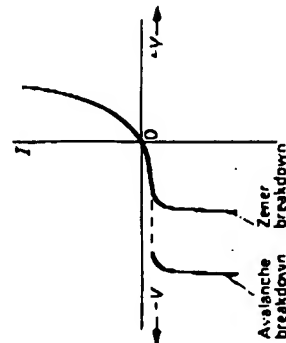


Fig. 30

## Varactor diode

A  $p$ - $n$  junction diode with reverse bias can function as a variable capacitance. Due to the reverse bias, the charge carriers are drawn away from the junction as in Fig. 31(a). The region on either side of the junction is therefore depleted of charge and is called the *depletion layer*. The depletion layer has charges on either side of it and therefore behaves as a parallel plate capacitor.

The thickness of the depletion layer varies with the applied bias and a variable junction capacitor can be produced by varying the reverse bias. For an abrupt  $p$ - $n$  junction, the variable capacitance  $C_j$  of the junction is given by

$$C_j = \frac{C_0}{(V_i + |V|)^{1/2}}$$

where  $C_0$  is a constant depending on the amount of doping and junction area,  $V_i$  is the internal junction voltage of about 1 V and  $|V|$  is the modulus of the reverse bias voltage.

In the case of a graded junction diode, the square root sign is replaced by a cube root sign. Typically  $C_j$  varies between 50 pF and 100 pF for an abrupt junction and between 5 pF and 50 pF for a graded junction. A typical characteristic is shown in Fig. 31(b).

The varactor diode finds application in FM modulators for producing an FM signal, or in parametric amplifiers for low-noise amplification.

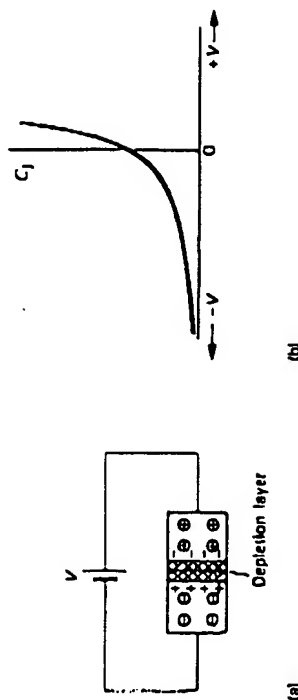


Fig. 31

Tunnel diode<sup>9,14</sup>

If a  $p$ - $n$  diode is doped heavily in both the  $p$ -region and  $n$ -region, the diode has a *negative resistance* over part of its characteristic when forward bias is applied. The negative resistance effect can be explained readily using quantum-mechanical principles.